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TREATMENT OF PAINT BOOTH EMISSIONS USING A MICROWAVE CONCENTRATOR/BIOFILTER INTEGRATED SYSTEM

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Treatment of Paint Booth Emissions Using a Microwave Concentrator/Biofilter Integrated System

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ABSTRACT

The passage of the Clean Air Act Amendments (CAAA) has justified the need for increased investigation into the treatment of air streams containing volatile organic compounds (VOCs) and hazardous air pollutants (HAPs). In cooperation with Tyndall Air Force Base (Panama City, FL), ENVIROGEN (Lawrenceville, NJ) and CHA Corporation (Laramie, WY) have recently begun the installation and operation of a pilot-scale integrated microwave concentrator/biofilter system for the treatment of solvents discharged from spray paint booth operations.

In the first phase of the treatment process, a ventilated air stream (3,000 SCFM) containing solvents from spray painting operations is passed continuously through a granular activated carbon (GAC) moving-bed adsorber. The contaminants treated include methyl ethyl ketone, methyl isobutyl ketone, toluene, ethylbenzene, and xylene. Some chlorinated solvents at lower concentrations are also present. The carbon adsorbent serves as a solvent vapor concentrator. The solvent-saturated GAC is regenerated via microwave energy in a separate regeneration vessel. The microwaves cause the solvents to rapidly desorb from the GAC and return to the vapor phase. The solvent vapors are removed from the regenerator by a small stream of nitrogen purge gas and transferred to storage tanks.

On a continuous basis, solvent-laden nitrogen from the storage tanks is supplied to an ENVIROGEN biofilter along with approximately 100 SCFM of air. ENVIROGEN's biofilter is an air pollution control system in which contaminated air is passed through a bed of organic filter material containing a natural flora of microorganisms. The contaminants are degraded by the microbes on the filter bed into innocuous products of carbon dioxide and water. Typically, the clean air exits the filter bed and is emitted directly to the atmosphere. To ensure optimal degradation of the contaminants by the microorganisms, the filter bed must be maintained in a moist state. The filter bed

moisture level is maintained by pretreatment of the air through a humidification chamber and a water irrigation system located within the biofilter vessel.

This paper describes the system design and operating characteristics. Critical findings at the pilot-scale, overall system performance, and the potential applicability at the full-scale system will be discussed at the conference.

INTRODUCTION

The treatment of contaminated air [volatile organic compounds (VOCs) and hazardous air pollutants (HAPs)] has received increased attention in recent years, largely as a consequence of the 1990 Clean Air Act Amendments (CAAA). VOCs effect the nitrogen dioxide (NO_2) photolytic cycle, and also contribute to the formation of ground-level ozone and other oxidants, the major components of photochemical smog.[1] The CAAA require a significant reduction in HAPs released from major emission sources.[2] There are 188 HAPs currently listed under Title III of the CAAA targeted for reduction, including the common paint solvents toluene, xylenes, and methyl ethyl ketone (MEK).[2]

The available options for VOC and HAP reduction from individual sources include: (1) process changes; (2) raw material re-formulation; and/or (3) installation of point source control measures. Existing point source control options include: (1) wet scrubbing; (2) carbon adsorption; (3) thermal oxidation; (4) carbon adsorption; and (5) biological treatment.

Biological air treatment is a relatively recent development in the United States. Traditional vapor scrubbing, thermal incineration, catalytic incineration, and adsorption to activated carbon are typically used to treat contaminated air. However, all these methods are potentially more expensive than biotreatment.[3,4] In addition to economic issues, another drawback of both traditional vapor scrubbing and adsorption to activated carbon is that these methods do not destroy the toxic contaminants, but merely transfer them from one medium (air) to another (liquid or solid). Further processing is necessary to destroy the contaminants. Biotreatment processes are environmentally friendly, and produce only non-hazardous by-products such as additional biomass, water, and low levels of carbon dioxide. No carbon monoxide, nitrogen oxides (NO_x), sulfur oxides (SO_x), or thermal pollution are produced.

Most biological air treatment technologies commercially available are fixed-film systems that rely on growth of a biofilm layer on an organic support such as compost, peat, or wood chips (biofilters). If designed properly, these systems combine the advantages of high biomass concentration with high specific surface area for mass transfer.[5]

A key to the success of a biofilter system is that a thriving microbial population is maintained. Numerous point source emissions generate transient, unsteady-state loads. Therefore, the intermittent operation of these point source emissions may not provide sufficient organic loading to sustain a biofilter reactor. One potential solution to this problem is to provide an adsorber/concentrator system as a preliminary step to provide the biofilter with a constant load of organics. In general, granular activated carbon (GAC) adsorbs solvent vapors and other volatile organic compounds (VOCs) at removal efficiencies of greater than 99 percent. The adsorption capacity of GAC is higher than 10% for solvents used in spray painting operations. The GAC bed removes and stores solvents in air and can be used as a concentrator for the biofilter operations. Because GAC is an excellent microwave energy absorber, rapid and controlled regeneration of saturated carbon is possible to supply a constant stream of air containing a steady concentration of solvents.

OBJECTIVES

This project was a collaborative effort between ENVIROGEN (Lawrenceville, NJ) and CHA Corporation (Laramie, WY), in cooperation with Tyndall Air Force Base. The project was funded through the Small Business Innovative Research (SBIR) Program. The purpose of this research effort was to treat VOC and HAP emissions generated intermittently from a spray paint booth booth located at Tyndall AFB (Panama City, FL). The generation of a transient, unsteady-state load of organics requires that a concentrator/biofilter treatment system be implemented. This experiment will provide insight as to the applicability of such a treatment system to spray paint booth operations. The establishment of essential operating parameters and vital performance results will allow for the eventual scale-up of the system.

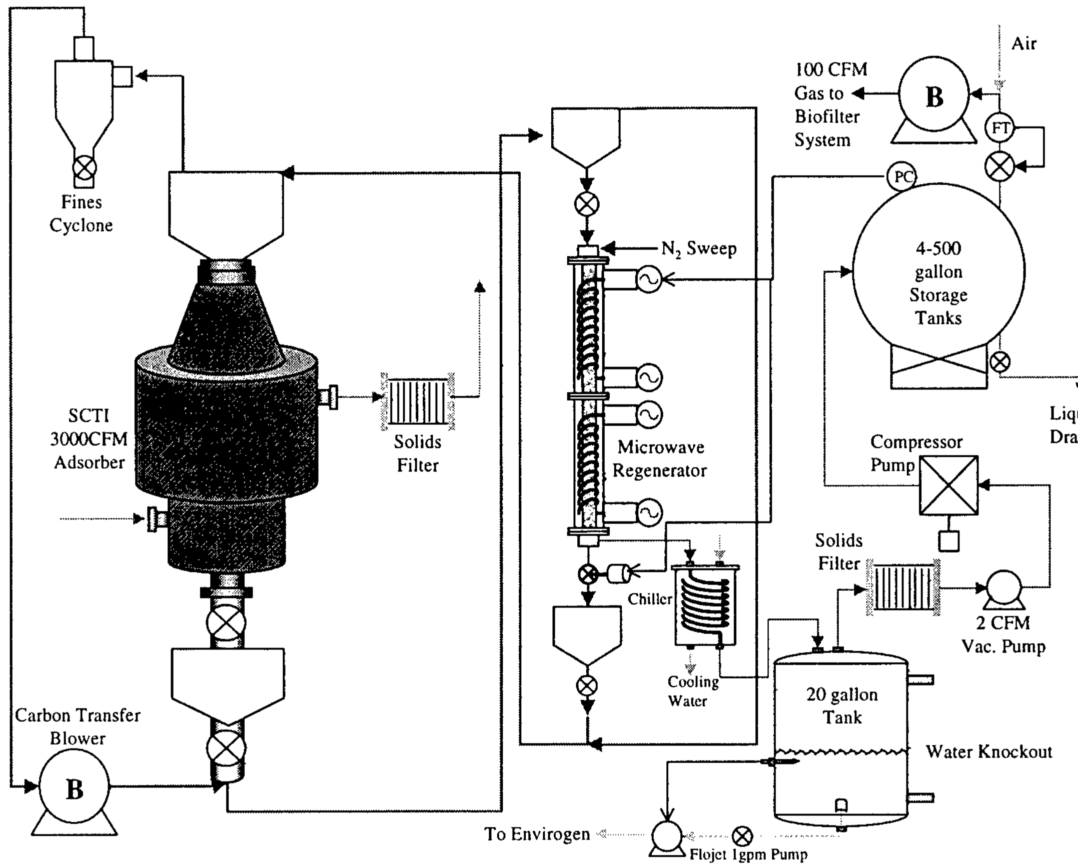
EXPERIMENTAL SET-UP

Concentrator/Regenerator System

The major components of the concentrator/regenerator system include the adsorber, microwave regenerator, compressor, pneumatic carbon transfer system, system monitoring/control hardware and software, the carbon, and the storage vessels.

A ventilated air stream (3,000 SCFM) containing solvents from spray painting operations is treated continuously by the GAC moving-bed adsorber (Figure 1). This adsorber is a two stage radial apparatus. In the adsorber, the solvents are removed from the ventilation air by adsorption onto the GAC. The carbon adsorbent serves as a solvent vapor concentrator in this type of process. It removes the spray paint solvent vapors from the large air steam, and concentrates them into a smaller stream that is more easily treated. The concentrated stream produced during regeneration of used GAC usually has a flow that is less than 1% of the flow of the original contaminated air stream. The GAC is periodically fed through the adsorption unit via a feed hopper at the top and travels downward.

Figure 1. Schematic of the concentrator/regenerator system.



The used GAC exits through a star valve at the base of the adsorber and regenerated GAC is fed into the top of the absorber. The saturated carbon is transported to the top of the microwave GAC regenerator by a pneumatic carbon transfer system. The conveyor air is passed through a cyclone to remove any entrained solid particles during carbon transfer (store >0.5um carbon fines).

The GAC loaded with solvents is fed into the regenerator by a feed hopper at the top of the regeneration system. Regenerated GAC exits through a rotary valve at the base of the regenerator. The regenerator operates as a moving bed and regenerates the saturated GAC via microwave energy. The basis of the microwave regenerator design is a tee reactor in which a 2.36-inch quartz tube is housed within a 5-inch aluminum reactor body. Microwaves are supplied by home oven magnetrons and transmitted to the saturated carbon flowing within the quartz tube by a launcher, waveguide and finally ¼-inch diameter copper helix that is wrapped around the length of the quartz reactor tube. The copper helix evenly distributes the microwave energy along the length of the quartz reactor tube and promotes consistent solvent desorption. The microwave regenerator has 4 microwave inputs. Each microwave system includes a magnetron, launcher, directional coupler, adjustable short, power supply, and short section of 340 waveguide with rectangular flanges. The microwaves cause the solvents to rapidly desorb from the GAC and return to the vapor phase.

The desorbed solvent is removed from the regenerator by nitrogen gas sweep. In this double tee-reactor with central gas porting the nitrogen sweep gas enters the system in two locations and exits from either end as well as a 2-inch central gas exit port. The gas porting is vital so that the desorbed solvent can be quickly removed from the reactor so that re-adsorption does not occur.

After the nitrogen/solvent gas mixture exits the microwave regenerator it passes through a chiller/water knockout tank. The knockout tank can drop out 67% of the water removed from the saturated carbon during regeneration. A 20-gallon tank and a float level controller are used for the water knockout. This water is added to the ENVIROGEN water supply for either the humidifier or the biofilter. After the majority of the water has been removed, the gas exits the knockout tank and passes through a solids filter that protects the vacuum pump and compressor.

The small nitrogen stream, 1 SCFM, containing a high concentration of solvent is compressed into four 500-gallon storage tanks. These tanks allow for a continuous feed to the biofilter because regeneration is periodic rather than continuous. A small stream of solvent laden nitrogen is withdrawn from the storage tank and combined with 100 SCFM air to supply solvent vapor to the biofilter.

The concentration of the gas exiting the storage tanks is monitored continuously with on-site analyzers and the flow to the biofilter is adjusted accordingly. The storage tanks are pressure regulated and the biofilter feed rate is controlled by an air actuated gas flow valve coupled to an I/P Actuator controller. The gas flow is monitored by a flow meter.

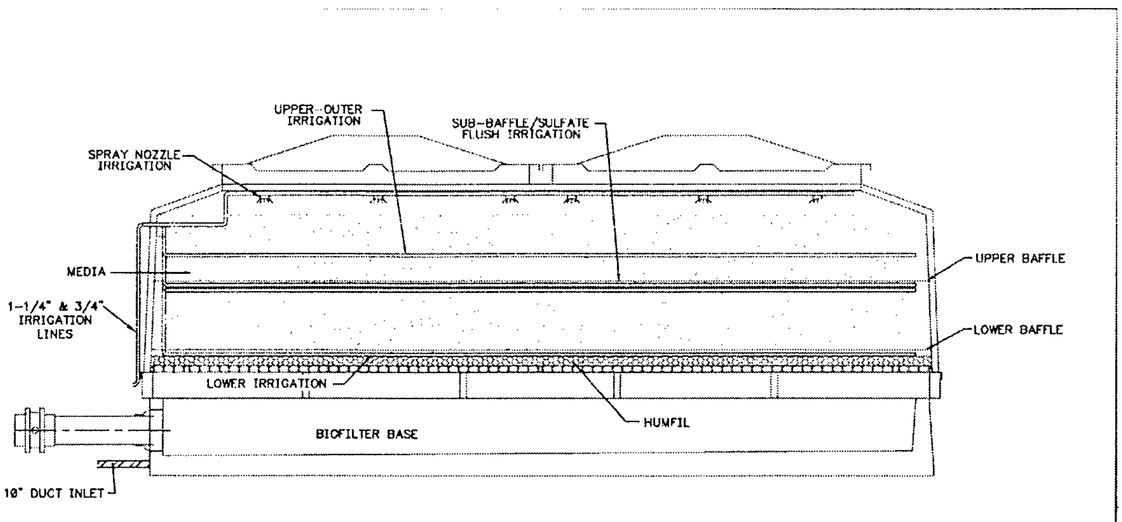
The control system, hardware and software, was purchased from National Instruments. This system is capable of monitoring and controlling the CHA paint vapor concentrator and ENVIROGEN biofilter with little human attention necessary.

Biofilter

ENVIROGEN has installed a P600 series biofilter at Tyndall AFB (Figure 2). The P600 series biofilter contains 600 cubic feet of filter media (proprietary compost blend mix) that treats 100 SCFM at a 6 minute contact time. The entire system is composed of a control panel, blower, humidification chamber, and biofilter vessel that sits atop a 40'x8'x4' trailer (Figure 3).

The contaminated air from the concentrator unit enters the blower at 100 CFM. The air is passed through the bottom of a humidification chamber where the air is saturated with water. The saturated air passes through the bottom of the biofilter reactor system through a plenum. The air is passed upward through the media bed where it is treated and released to the atmosphere. Weep hoses are provided at various heights along the filter bed to provide substantial moisture control. Water is drained from the bottom of the reactor. A portion of this water is wasted to a drain while the rest is combined with fresh water and recycled back to the filter bed. This recycling of the wastewater provides nutrient return to the system and minimizes wastewater generation.

Figure 2. Schematic of the biofilter reactor.



METHODS

During the operation of the system, numerous types of air and water analyses are conducted both on-site and off-site to determine and maintain system performance. Off-site analyses are performed as a quality assurance/quality control measure for the on-site data.

Air Analysis

On-site air analysis of total organic concentrations is performed using three Eagle™ EM-700 total hydrocarbon analyzers (Irvine, CA) that sampled continuously. The analyzers measure air concentrations at the inlet of the adsorber, before the biofilter (after storage tanks), and after the biofilter reactor. The instruments use methane as a calibration gas standard. The data obtained from the analyzers are automatically logged into a data acquisition system.

In addition, grab samples of air are also obtained on a periodic basis and are analyzed using Methods EPA TO-12 (total non-methane organics) and EPA TO-14 (aromatics, ketones, etc.). Composite inlet and outlet air samples are collected into passivated Summa® canisters and shipped off-site to AirToxics, LTD. (Sacramento, CA) for analysis. In addition to measuring organics, carbon dioxide gases are also measured using Method ASTM D-3416.

Water Analysis

Water samples for on- and off-site analysis are periodically collected from the biofilter in order to assess the nutritional requirements of the microbes in the reactor. On-site analysis includes the use of HACH® (Loveland, CO) measuring kits for the analysis of ammonia-nitrogen, nitrate-nitrogen, phosphate-phosphorus, hardness, and pH. Off-site analysis is performed at the ENVIROGEN Laboratory (Lawrenceville, NJ). Off-site sample analysis includes VOC (EPA 8260B), ammonia-nitrogen (EPA 350.2), nitrate-nitrogen and ortho-phosphate (EPA 300), phosphorus (EPA 365.3), total Kjeldahl nitrogen (EPA 351.1), and total organic carbon (EPA 415.1).

RESULTS AND DISCUSSION

Installation and operation of the system has recently been completed. Initial performance data is not available but will be presented at the conference. A number of factors and variables are critical in the system obtaining optimal performance. One key operating parameter in the regeneration system that requires extensive monitoring is the amount of solvent laden nitrogen gas available for supply to the biofilter from the storage containers. It will be necessary to vary this flow to constantly provide the biofilter with at least 50 ppmv as methane. However, adequate reserves must remain available in the storage tanks to account for extended downtimes of the spray paint booth operation. The rate of carbon regeneration (# of times/week) will dictate the amount of organics being supplied to the storage tanks, and eventually, the organic concentration available to the biofilter.

A second key operating parameter will be the amount of recycled water provided to the biofilter. This amount will change over time as the water characteristics are altered by the biological processes. The operator of the system will attempt to maximize the portion of wastewater that is recyclable. This will minimize both the costs for wastewater disposal and the removal of essential nutrients from the system. However, care will need to be exercised to avoid reintroducing extremely saline water to the system.

CONCLUSIONS

ENVIROGEN and CHA Corporation, in cooperation with Tyndall Air Force Base, have implemented a concentrator/biofilter system at Tyndall AFB for the purpose of treating spray paint booth emissions. Typical spray paint booth emissions have been shown to be readily treatable using biofilter treatment systems. However, if constant organic loading is not introduced to a biofilter, an effective microbial population may not be maintained. Typical spray paint booths provide a transient, unsteady-state organic load. Thus, the addition of a concentrator provided upstream of a biofilter can eliminate these unsteady loading conditions so that the biofilter microbial population can thrive. Implementation and operation of the system have recently begun. The establishment of critical operating parameters and performance results will allow for potential scale-up. These parameters and results will be presented at the conference.

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KEYWORDS

Biofilters, volatile organic compounds, biological air treatment, emission control equipment, spray paint booth emissions